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ENTOPTIC PHENOMENA ASSOCIATED WITH THE RETINA

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ENTOPTIC phenomena may be induced by structures in the retina and adjoining chorio-capillaris or by structures anterior to the retina. Only the first of these groups will be considered in this paper. If it is assumed that the most distal part of the layer of rods and cones, namely, the outer segment, is the receptive structure for visible form, it is theoretically possible for this part of the rods and cones to see in some measure the shadows of all structures on or near the optic axis in front of it; and, since the distal part of the rods and foveal cones shows no distinct asymmetry of structure, there seems no good reason why this receptive part of the retina should not see objects behind it if these are sufficiently illuminated for the purpose. This power of looking backwards the retina possesses.

Retinal Vessels and Macula

The most easily demonstrable entoptic phenomenon associated with the retina is the retinal vessels themselves. The shadows of these are momentarily seen when light is thrown at a slight angle on the retina. By constant movement of the light they can be kept in view. The more parallel the beams of light falling on

the retina the more perfect is the picture of the retinal vessels perceived. A light source placed near the sclerotic, which sends out light rays in all directions, shows only the larger vessels, whereas an arrangement offering parallel rays to the retina demonstrates also the capillaries around the vessels. The distribution is seen to be the same as in the central part of an injected retina. The explanation of their visibility (*cf.* Wheatstone) usually accepted is that the obliquity of the light falling on the retina used to make them visible causes shadows to fall on the rods and cones unaccustomed normally to receive them. The explanation is not wholly satisfactory (*cf.* Jago). Thus the simplest way of viewing the central retinal vessels entoptically is to cause eccentric rotation of a pinhole in front of the pupil whilst gazing at a uniformly lit surface such as the sky. The minimal rapidity of rotation necessary to bring out the vessels well is about four per second. Cessation of the movement at any point causes the perception of the vessels to disappear immediately. It would thus seem that successive induction plays an important part.

Besides the retinal vessels the macula is seen at the same time, most clearly by the pin-hole method. Viewed by this method it has the appearance of an aster-like figure with somewhat curved lines running from a depressed centre. The lines are probably the curved nerve fibres originating in the foveal cones. They are the only structures of the retina, apart from the retinal vessels, which are distinctly seen in front of the rods and cones. The reason that other structures of the retina are not perceived by these methods is due to the overcrowding and superposition of cells in the different layers outside the macula so that no outline picture of them is possible. The blood vessels alone are perceptible because being less numerous, less transparent and less superposed, they exhibit more definite contours. That the foveal nerve fibres are seen is doubtless due to the absence of other structures and to the regularity of the narrow bundles of fibres giving visible outlines.

Chorio-capillary Circulation

A retro-retinal circulation, probably limited to the chorio-capillary circulation, may be indistinctly perceived, after experience of its normal appearance has been gained, by gazing intently, with relaxed accommodation, at any brightly lit uniform field. The luminous points to be referred to later are earliest and most easily seen; but on continuing the gaze these may disappear and be replaced by a darkened field in which circulation is observed. I first saw the chorio-capillary circulation whilst under the influence of mescaline, but it was only recognized as such after prolonged investigation with the microscope. If a microscope is arranged

to give the best lighting for resolution for any particular objective and the brightly lit field be gazed at for a short time, the field may become suddenly more or less dark. In a perfect observation it becomes very dark. Careful examination will then show a surging circulation in irregular sinuses, somewhat fern-like in appearance, of a dark reddish-grey colour, bounded by a black ground mesh-work and covering the whole field. Over the field may also be seen innumerable fine granules of black pigment; but not always. The effect lasts only a few seconds but it may usually be repeated several times, and after considerable practice many times. Certain conditions facilitate the observation. It is imperative that anything fixing attention should be absent; hence the microscope should be optically clean and the source of light well shaded from the eyes. As illuminant for these observations the oil lamp with bull's eye condenser possesses advantages. The unused eye should be kept open and directed towards a black background about 25 cm. away. An ordinary camera dark cloth may be used to cover the bright parts of the microscope and form the requisite background. In place of this background the eyeshade sold for use with the microscope may be employed, but is less efficient. Capped eyepieces, owing to the greater protection they afford, are better than the ordinary kind; and the long tube microscope is better than the short tube one owing to the greater comfort of observation and the more suitable distance of the projected visual plane. A low power eyepiece is advisable and a to-and-fro movement about the eye point is often helpful in initiating the change to darkground effect. The experiment requires a partially dark-adapted eye and is best made in an evening. A certain but small intensity of general lighting is, however, desirable. That obtained through the door from an ordinarily lit hall in an otherwise unlit room is usually sufficient.

When the retro-retinal circulation has been perceived, it can easily be projected on to a dark board at the usual distance of 25 cm. from the unused eye and could easily be drawn in outline were it not that the circulation is in turbulent motion and the outline constantly changing owing largely to its considerable depth. Perhaps the nearest representation to its appearance is that of a bunch of fern fronds blown by the wind. Curiously, the unused eye seems to be projecting the picture, since any disturbance of the vision of that eye causes the picture to disappear; but this is not always the case, since the retro-retinal circulation can be observed when the unused eye is closed. The circulation cannot, however, always be observed especially when the microscope is used. Occasionally only the pigment layer of the retina is seen; sometimes, even after considerable experience has been gained, no retro-retinal structure whatever can be focused, a difficulty particularly noticeable in anxiety states.

Provided the conditions of uniform illumination to one eye and an appropriate dark visual field to the other eye be maintained other arrangements may be used. A large short-focus lens placed slightly within its image plane from a brightly lit opal surface arranged in a blackened tube affords an equally easy method of observation, but the picture has not seemed to me so sharp as with the microscope. The circulation may also be observed in an interesting way by means of the slit-lamp as ordinarily used in a dark room. If a board covered with a black cloth be placed in front of the unilluminated eye and be tilted towards the slit-lamp to get the most suitable lighting, a dark tumultuous circulation may be discernable on it and by movement of the slit-lamp the Purkyně figures may be observed in the illuminated eye. The two circulations, so completely different, may thus be observed at the same time by the two eyes. The perception of the chorio-capillaris as a pressure phosphene will be referred to later.

The retro-retinal picture, even of the circulation only, is not always the same, because it is not always possible to get full resolution; and apart from the distance to which the picture may be projected, there seems at times to be some difference in the magnification under which it is observed. This difference is, perhaps, most noticeable when the circulation is seen as a pressure effect.

Retinal Pigment

Besides the chorio-capillary circulation pigment particles may also be seen at the same time covering both circulating blood and ground meshwork. The combination of circulation and pigment particles is the picture commonly seen by my right eye. It has been less constantly seen by my left eye. With this eye the circulation, or very rarely the pigment, may form the whole picture. But when the pigment has been seen alone it has appeared under greater magnification than when it has been observed with the chorio-capillaris. The pigment granules then looked rod-like and were not regularly distributed over the visual field. Both pictures are very beautiful and very different. The one is a picture of still life—minute black rods variously and unsymmetrically arranged on a buff-coloured billowy surface; the other is a foliaceous pattern of a restless surging sea. The latter is by far the commoner picture. The pigment picture has been seen very rarely and could not be reproduced at will. Recent attempts to obtain it after a long break in the frequency of observations have not been successful, except as imperfect presentations in combination with pressure on the eyeball. Still more rarely patches of the pigment layer were observed as though not more than 12 of the foveal cones were

in action; and on two or possibly three occasions out of many hundreds of observations the pigment in one of the pigment cells appeared to be under very great magnification—at least 500 diameters. In these observations the pigment seemed distinctly crystalline, appearing very much like the haemin crystals prepared for forensic purposes as seen with an oil-immersion objective. It was only observed for one or two seconds and in that time no movement, Brownian or other, was noticed. Zehender, who saw something similar, observed slow movement. Migration of pigment particles is, of course, well known to occur in lower vertebrates (*cf.* Kühne); and Smith describes a swift, jerky motion of the pigment granules in the cytoplasm of cultures of the chick's eye which were much accelerated by continuous exposure to light. Movement of the pigment granules in mammals, however, is not known with certainty to occur.

Luminous Darting Points

The earliest and probably the most commonly observed entoptic phenomenon of the retinal group is a succession of luminous points, sometimes called glancing or dancing points, darting in more or less regular pathways over the visual field. They are easily seen by looking at any strongly lit surface such as a snow field, a blue or grey sky, a whitewashed wall or a sheet of white paper with relaxed accommodation. The mercury lamp directed against a white reflecting surface is an easy way of demonstrating them. Their origin has been much debated. Good accounts of recent opinions are given by Scheerer, Ebbecke and Adler, and of older observations by Helmholtz. They are unquestionably cells circulating in blood vessels; but what cells and what blood vessels it is difficult to determine. The points are commonly seen in the earlier part of an observation which it is hoped will end in viewing the chorio-capillaris. If care is taken they may be observed up to the point of transformation from the bright field to the dark field of the chorio-capillary circulation. The observation is difficult to make and is most easily made with a mercury lamp and a suitable reflector. With practice the luminous points for a time may be seen, although less brilliant than usual, at the periphery of the visual field and, indistinctly, the chorio-capillary circulation at the centre; and it may even be possible to see them momentarily as dark points as the chorio-capillaris becomes more visually resolved. But the luminous points are not in the chorio-capillary circulation. They are not seen when this circulation is resolved fully. Moreover, they are too small in size and in velocity to be situated there, and their flight does not correspond to the

flow of this circulation. Nor are they in the retinal circulation of the nerve layer. Their size and velocity are too great for this position and their course is not that of the retinal vessels. This fact can be easily shown by observing these luminous bodies against the reflected mercury light with one eye and producing the Purkyně figures by eccentric rotation of a pin-hole in a piece of black cardboard before the other eye. The two kinds of objects are seen to be on different planes, the luminous points appearing further away and giving the impression of being more highly magnified. The pathways in which the luminous points move cannot be made visible, but from the jerky movements of the points in what appears to be a network of channels it may be assumed with great probability that the cells are circulating in capillaries; and the experiment mentioned above where the luminous points and the retinal vessels are projected at the same time, with an apparent difference in magnification, suggests the deeper layer of capillaries in the inner nuclear layer as their place of origin. This is the place assigned to them for different, and to me insufficient, reasons by Zehender, Abelsdorff and Nagel, Bühler, Gescher and Fischer. If here the points must be caused by red blood corpuscles, refracting and under some conditions possibly reflecting light on to the layers of rods and cones. They are far too numerous to be white corpuscles in a circulation of this kind; and rarely they may be seen in groups of two or even three. Sometimes lines of light may be observed which are probably strings of corpuscles. It has been said that the red corpuscles being biconcave discs could not refract light rays on to the rods and cones, but this supposition ignores the positions which red corpuscles may assume in a capillary channel. Further, it is more difficult to explain physically the occurrence of these points, as dark points, if they are regarded as white than as red corpuscles. They may be seen as dark points against the sky, but the reversion is most easily effected by dark-adapting the eye or pressing on the eyeball and then gazing at the reflected mercury light. Usually the points are first seen as short dark lines, then as light points with a very short dark tail, and finally as the usual luminous points often with a short light tail. The tails, which have also been observed by others (*cf.* Thomsen), are probably of the nature of after-images.

Pressure Phosphenes

The fact that the retina can look backwards throws a new light on these occurrences, the chief factors in the production of which appear to be the pigment granules and the retro-retinal circulation. Thomsen says "there are as many pressure phenomena as folk

in the world" but, although variations in appearance even under apparently similar conditions are considerable, my own pressure phosphenes are fairly constant and, apart from some fantastic imagery in some of the descriptions in the literature, would appear to be not dissimilar from those of other observers. Only a few points bearing on the present investigation will be discussed. The simplest experiments are those made during the night after sleep by using uniform or increasing pressures over the eyeball in an antero-posterior direction. The phosphenes produced by heavy localized lateral pressure are more complex because among other things the retinal vessels can be seen in this way and even, as Vierordt showed, the retro-retinal circulation. The phosphenes obtained during daylight are influenced by the varying photopic state of the eye and are more easily obtained and more brilliant than those of the scotopic eye. The essential components of pressure phosphenes seem to be dark or light, sometimes coloured, patches, stationary or in motion; brilliant static or moving points of light recalling a spinthariscopes effect; and, under certain degrees of pressure, regular geometrical figures such as hexagons, which may for a time cover the whole or greater part of the visual field, but may be interspersed and eventually replaced by the appearance of coloured dust (mostly bluish shades) on a dark background, similar to the appearance of a silver colloid solution as seen with a dark-ground condenser, except in the absence of Brownian movement of the particles. Fantasy figures such as the "Schneckenrechteck," the snakes and worms mentioned by Purkyně, do not appear to have been frequently observed. Czermak associates them with other geometrical formations (hexagons, etc.), while Thomsen attributes their appearance to the retinal blood vessels. If these figures are of circulatory origin they are probably out-of-focus effects of the chorio-capillary circulation variously interpreted psychologically.

Of these fundamental components of pressure phosphenes the static points and scintillating stars are probably due, directly or indirectly, to the pigment granules. The effect has been attributed to a pressure stimulation of the rods and cones by the pigment granules, but since the most brilliant appearances are obtained, not during pressure but, if this has been not too prolonged, immediately after its release, this explanation is improbable. Moreover, repeated successive pressure on the eyeball of a dark-adapted eye is associated with a diminution in the brilliance of these luminous points. It is more probable that the retinal pigment is a reservoir of energy (its function and properties need not for the present purpose be more clearly defined) which by the emission of electrons is capable of producing the appearance of light (*cf.* Schanz). Under normal conditions the energy being con-

stantly liberated is small and the particles being outside the posterior focus, if we may use that term, of the rods and foveal cones, the liberated energy is perceived only as a diffuse light of small intensity which may be the so-called self-light of the eye. But, when conditions are altered by pressure, a greater number of electrons may be emitted and this greater activity may manifest itself in more intense light points which, when brought into the approximate focus of the rods and cones by the continued pressure, are perceived as star-like lights. Adjustment of this condition to an optimum is more likely to occur after relaxation of pressure and this is the time when the brilliant stars are seen most clearly. Moreover, the greater activity caused by the pressure is likely to lead to temporary exhaustion which would explain the diminution and disappearance of these points of light with repeated pressures.

Another kind of light point may also be observed after discontinuing prolonged heavy pressure on the eyeball. These points, which are less luminous than the vibrating points, move rapidly across the visual field. They are best observed in the small dark patch corresponding to the area of the fovea. At one period during the return to normal the circulation of small discrete slightly luminous bodies, suggestive of blood corpuscles may be seen. Living blood corpuscles or any blood pigments have not, as far as I am aware, been credited with properties allied to chemi-luminescence; fluorescence, which appeared to be independent of the quality of the food, has been observed in the blood of certain parts of the silkworm during the spinning of the cocoon (Policard and Paillot) and A. and L. Gurwitsch and Sorin have stated that the circulating blood of the frog gives off mitogenetic rays; but their experiments—the exposure of the living tip of an onion rootlet to the anterior abdominal vein of a frog—do not carry conviction. It does not, however, seem to me impossible that the circulating blood in the capillaries of the exposed skin may absorb energy from the rays which penetrate to them and emit it as resonance radiation in fluorescence and that this energy in the blood of the choriocapillaris may be transformed in the retina into a form perceptible as light. Granular leucocytes show distinct fluorescence in ultra-violet light and the blood, like other tissues which act as protective agents to ultra-violet light, absorbs it and degrades it to visible light (Radley and Grant).

The dark patches and surrounding haloes have been explained by Thomsen as being due to the anaemia induced by the pressure with some associated environing hyperaemia; and apparently he believes that both choroidal and retinal vessels are involved. The

severest pressure that can be borne does not appear to influence materially the chorio-capillary circulation, but that the capillaries of the inner nuclear layer are to some extent readily influenced by pressure can be shown, if we accept them as the seat of the luminous points previously noticed, by observing the effect of pressure whilst gazing at the reflected mercury light. Even gentle pressure causes marked slowing of their movements, but complete cessation of movement is not readily obtained. But the retinal circulation can hardly be effective in inducing these colour patches since the circulation supplies the retina only to the inner nuclear layer and cessation of it, even if it occur, would scarcely act sufficiently rapidly on the conducting paths of the visual impulses to produce the effects experienced. Nor is it easy to understand how congestion, apart from hypothetical pressure, could induce haloes or other light effects of the nature of those seen in phosphenes. Also against these ideas is the fact that continued or deeper pressure can be adjusted to produce luminous patches where dark patches existed before. The most brilliant of these light patches are seen in the centre and correspond to the macular area. The centre of this area corresponding to the fovea may show, during increasing pressure, considerable brightness and even some evidence of an underlying circulation, but it more usually appears as an irregular dark patch with a bright surrounding halo corresponding to the outer thickened rim of the macula. This bright ring is probably caused by mechanical pressure on the nerve fibres coming from the fovea; but the matter has not been further investigated.

As already mentioned, Vierordt stated that the chorio-capillaris can be seen by deep pressure on the eyeball. Its visibility is perhaps most easily induced by pressure on the external canthus while the eye endeavours to look outwards, but in that case the retro-retinal circulation is confined to an arc or crescent at the antipodal area. The circulation is better seen, if it can be observed in this way, when the pressure is directed backwards but it is never so distinct as when resolved by the light of the microscope and the magnification under which it is seen is often considerably less, possibly because the plane of projection is nearer. Indications of the retro-retinal circulation are more easily obtained as a pressure effect than with condenser lighting and anyone prepared to take the risks and suffer the discomfort of prolonged pressure should be able to see it. The appearance is variable, as indeed it may be with all forms of observation, unless complete resolution is obtained. Not infrequently it presents a dark marbled appearance; at other times the small part of the circulation seen appears self-illuminated. After heavy pressure, well-defined, irregular brownish patches resembling in some degree chromatophore cells with a more distant

ill-defined rapid circulation may also be transiently observed. They are probably a view of a plane just anterior to the chorio-capillary circulation.

The most easily produced pressure phosphene is that induced by very gentle pressure on the external canthus when the eye is turned nasalwards. An antipodal dark patch with narrow surrounding halo is produced which does not overstep the shadow of the naso-orbital arch. This phosphene is more easily produced in light-adapted than in dark-adapted eyes and according to Klein it disappears on rubbing. According to him it takes longer and more vigorous rubbing to cause its disappearance in light-adapted than in dark-adapted eyes. From these experiments Klein concludes that the primary pressure effect cannot be behind the rods and cones, and he evolves a theory of vision by which he believes all pressure phosphenes are explained. It is, however, difficult to maintain uniformity of pressure in these experiments and in respect of disappearance of the halo my own observations do not confirm those of Klein. Klein assumes that only intermittent stimuli can excite sensory endings such as the rods and cones, and suggests that two or possibly more layers of the retina in front of the rods and cones are able to convert a constant stream of light rays into an intermittent stream (about 70 per second). In these layers exist unknown light-sensitive substances which undergo assimilation and dissimilation. The latter produces the self-light ("Eigenlicht") of the eye. When this intermittent light is equal in power to any external light falling on the retina, the visual mechanism cannot be affected since there is no change of stimulus, consequently there is a perception of blackness; if the two differ in power there is an intermittent stimulus falling on the rods and cones which is capable of transmission and brightness results. There are some difficulties in accepting the theory and the correlated explanations, but the question is too complex for brief discussion. Klein uses it to explain the luminous appearance of the larger retinal vessels which may often be induced by suitable, usually heavy pressure with rubbing on the eyeball, especially at the external canthus. He gives a characteristic figure (*Taf.*, Vol. IX, Fig. 3, 1910). If the effect is obtained the vessels may be observed as black cords (negative after-image) when the pressure ceases. The same luminous appearance of the retinal vessels may also be observed when the slit-lamp is moved from a sclerotic to a corneal position at a point about the sclero-corneal junction, an effect which is difficult to reconcile with Klein's views.

The geometrical forms seen entoptically, whether as pressure phosphenes or otherwise, have been discussed by Purkyně, Thomsen and others, but no satisfactory solution has been suggested. The hexagonal types observed during pressure cannot

be due to the retinal pigment cells for the hexagons of pressure phosphenes vary greatly in size, often diminishing as a perspective effect, and are not accompanied by visible pigment granules. In my own eyes they are commonly associated with irregular black patches dotted with coloured particles which with continued pressure may cover the whole field. Repeated pressure on the eyeball is also associated with diminution in intensity and final abolition of these geometric forms, a fact which points to the pigment granules as an important factor in their causation. These geometric forms observed during pressure arise from the regularity in structure of the rod and cone layer. The diameter of the foveal cones (2.5μ) is not many times that of a wavelength of light (0.6μ approximately), consequently the energy perceived as light given off, say by the pigment granules, may have a relatively wide angle and various geometric forms are possible. The diminution of these geometric forms on repetitions of pressure may be associated with the diminution in the luminosity ascribed to the pigment particles under similar conditions.

The appearance of coloured dust on a black ground is difficult to explain. The particles show no Brownian movement and it is, therefore, improbable that the appearance is due to a colloid structure highly magnified whilst their irregularity in size and position preclude these dots being regarded as a projected picture of planes of rods and cones.

Self-light of the Eye

The "chaos lumineaux" which is experienced when the eyes are closed and after-images have died away, has also not been satisfactorily explained. It is of two types:—(1) A uniform dark greyness which is experienced in the completely dark-adapted eye as seen after prolonged sleep; (2) luminous clouds, generally of a violet colour, moving in waves centripetally or centrifugally. The greyness which may be regarded as the fundamental self-light of the eye, has a uniform distribution and hence it is not surprising that the cause of it should have been sought for in the circulation. Thomsen believes that it arises from metabolic processes occurring in the blood circulating through the eye and points to the effect of CO_2 on the respiratory centre; but he brings forward no proof of such an action. Zehender, basing his views on Pflüger's metabolic work, believed that the self-light was produced by cell oxidations apparently of retro-retinal structures; whilst Klein, as already mentioned, apparently regards it as associated with the metabolism of light-sensitive substances in some of the retinal layers. For psychological purposes a central

action has been assumed (G. E. Müller), but without any supporting experimental evidence and with clinical evidence of questionable value. It is difficult to conceive of tone in a visual centre unless there is something to induce and maintain it, so that if a central origin of the self-light be assumed we are driven to accept the state of greyiness as a rest state of the visual centres. Against this view is the fact that an almost infinitesimal amount of light—Joly thought that one electron might suffice to stimulate a cone—will produce in complete dark-adaptation a distinct sensation. Previously it has been suggested that the self-light might originate in the pigment granules of the retinal epithelium, and under pressure phosphenes it was stated that the retro-retinal circulation may show self-illumination. Two sources, therefore, seem available to explain the self-light of the eye. The energy required to produce the fundamental greyiness of the intrinsic light must be extremely small and it is consequently difficult to devise observations or experiments which will decide between these two possible sources. The pigment granules seen with the chorio-capillary circulation are black and emit no light; but in my experience retro-retinal structures, except as a pressure effect, are only seen in an environment of light more intense than that necessary to produce self-light. Let us consider the other form of the intrinsic light of the eye, namely, the moving violet clouds which by some are also regarded as fundamental to the self-light. The clouds are more noticeable on attention and they show a deeper violet hue when observed after exposure to bright daylight than when observed in the darkness of the night after prolonged sleep. The variation in hue of the clouds with increasing dark-adaptation seems to be very similar to that observed in passing from the middle violet of the spectrum to the ultra-violet with a spectrophotometer. If we attribute the self-light to some property of the retinal pigment allied to chemi-luminescence this difference might be explained by the cumulative effect of light during the day upon the pigment granules; but it is less easy to explain the rapid wave motion of these violet clouds, which is usually a characteristic feature, by the assumption that they are produced by the pigment granules. Sometimes these violet clouds may be seen in the field of the microscope when this is lit during a bright day from a window. With difficulty the chorio-capillary circulation and the retinal pigment may be seen at the same time, although indistinctly. The violet clouds then seem to be over the circulation, their contours seem to follow those of the circulation and their velocity appears to be similar to that of the circulation. The circulation, in fact, seems to be directing the movements of the clouds. But since the clouds when observed appear to be constantly changing form and position and to be in a plane anterior to the circulation they

cannot be merely a presentation of light in the circulation. Some other factors must be involved. W. Marshall believes that physiological fatigue plays a part. Santonin, when it causes xanthopsia increases these violet clouds in the eye. Its action, apparently one primarily upon violet perception, is probably retinal in origin and due to the transformation of santonin to some other substance (W. Marshall). One of his experiments is of fundamental importance to the present discussion. A subject had his eyes completely protected from light for 40 minutes; an injection of 10 mgm. santonin in solution was then given into the median basilic vein, the time taken by the injection being 45 seconds. "About 20 seconds after the commencement of the injection, that is, while it was still in progress, the subject remarked that the violet clouds were increasing rapidly in intensity and 10 seconds later exclaimed that he saw a brilliant violet field traversed by numerous brilliant moving stars. From this period the violet diminished in brilliance and was less marked when the injection terminated. The diminution in intensity continued and two minutes after the beginning of the injection was manifest merely as a glow. The stars were still seen, but they also soon faded away." A control experiment in which the same dose was given while the eyes were kept open produced practically no symptoms. The two points in this experiment bearing on the present enquiry are the transient flare up of light in eyes completely in the dark and the temporary brilliance of the luminous points. They show that in the absence of any light entering the eyes the appearance of light may be produced through the circulation. For the second symptom W. Marshall suggests "a temporary self-luminescence of the blood corpuscles induced by santonin" a result which "could only be attained by an interaction with some constituent ejecting sufficient electrons to produce luminescence. Such an interaction might also explain the brilliant violet light seen in the dark-adapted eye." Zehender saw luminous points in the dark, but he believed that the pigment emitted sufficient light to make these points visible. I have observed luminous points in comparative darkness, as after closing the eyes in dim twilight, but have not been able to determine whether they were identical with the darting luminous points previously considered. The most conclusive evidence that the retro-retinal circulation is able to produce the perception of light is found in Vierordt's experiment already mentioned, namely, that by proper pressure on the eyeball parts of the chorio-capillaris, usually over a small area only, appear luminous. From these observations it is difficult to avoid the conclusion that the retro-retinal circulation plays some part in the production of the self-light in the eye however it may be produced.

At this point reference may be made to the visual purple, since it has been said to be visible entoptically and thus might be a factor in the causation of self-light. The references cited are Tait, Boll, Ewald and Edridge-Green. Tait's "Note on a Singular Property of the Retina" is based on the observation that on awakening during the night a not very bright gas jet with a ground glass shade seemed to be surrounded for a second or two by dark crimson. He got skilful in reproducing this effect but it only occurred at the instant of awakening. He thought that probably the retina, or nerve cells with it, sleeps and on awakening portions connected with the lowest of primary forms of colour are first to come into action. Ewald first suggested that this appearance might be due to the visual purple; and, in view of the wide acceptance of his idea it is desirable to summarize his experiments. He observed on opening his eyes after awakening in the morning a black vessel figure (Purkyně's figure) on the ceiling which with practice he learned to observe with greater clearness; and eventually he saw yellow flecks in the neighbourhood of the fixation point which disappeared in less than two seconds. Wishing to examine this appearance with greater exactitude he asked his servant to throw a thick black cloth over his head before he awoke and after gaining full consciousness his eyes were covered by closely applying his hands and the cloth was removed. Directing his gaze to the ceiling his hands were removed quickly and replaced. He saw the two larger vessels which festoon above and below the macula and also a darkish yellow patch in the centre which he thought was the macula. The yellow patch was surrounded by a rose-coloured halo shading off almost to white at the blind spot and the festoon of vessels and having a diameter corresponding to about 5 mm. on the retina. The appearance is shown in a coloured figure (Fig. 9). It disappeared before the yellow patch and was only observed in a completely rested eye. No trace of it was seen after an hour's rest in a dark room during the day. The appearance corresponded so well with that of a central part of a freshly extirpated human retina still containing the visual purple that he thought the rose-coloured surround must be an entoptic appearance of the visual purple, although he mentions that Kühne found no rose-coloured appearance in mammalian eyes carefully removed in sodium light. He discusses the possibility that the colour might be due to the blood in the retinal or choroidal vessels, but rejects the idea that it is caused by the retinal vessels since the larger vessels appear black owing to their thickness while the colour produced by blood in the capillaries would be reddish-yellow and not rose-red as observed. And he rejects a choroidal origin because the effect is seen only in a rested eye, with presumably completely regenerated visual

purple, capable of being affected by such weak stimuli. Two comments on Ewald's observations are offered:—(1) The rose-coloured patch is not limited to the environment of the macula, but may be seen in the position of the macula itself where visual purple is believed to be almost absent. This appearance I have seen on awakening during the night and switching on an 8-watt electric light with parchment shade about a foot from the eyes while the eyelids were still closed. (2) Since the visual purple probably originates in the retinal pigment and does not extend in front of the rods and cones it would seem that if it can be observed entoptically it must be seen by the extra-macular rods and cones looking backwards while the yellow pigment of the macula is perceived by the foveal cones looking forwards, a Janus effect of adjoining similar units which it is difficult to conceive. Visual purple is not confined to the immediate neighbourhood of the macula and Ewald explains the limited field of the rose-coloured patch to the diminished sensitivity of the peripheral retina for red, a limitation which does not seem to agree with Boll's observation quoted by Ewald in support of his views. Boll (p. 20) noticed that the ophthalmoscopic picture of the retina is more intensely red when seen immediately after an individual awakens in a dark room in the morning than it appears during the day. Several factors may be involved in the explanation of this difference, but it is not probable that an almost imperceptible layer of visual purple can be perceived in the relatively intense red of the retinal field.

Edridge-Green's evidence for the entoptic visibility of the visual purple is of a somewhat different kind. He observed, in a not too bright room, whirling currents when the eye was partially covered. He concludes that these currents cannot be due to vessels because the centre of the retina, where the greatest movement is seen, is free from vessels and he interprets the phenomenon as currents of visual purple flowing into the external fovea. As the chorio-capillaris adjacent to the fovea has been seen by at least three people independently, Edridge-Green's objection does not seem to be valid; and, having observed this circulation in its many unresolved forms I have no doubt whatever that the figure (Fig. 5) given in his paper to illustrate these currents is an out-of-focus appearance of the retro-retinal circulation. The main objection to Edridge-Green's explanation is the fact that these whirling currents illustrated, indistinct though they be, are visions of form; and it is difficult to understand how a picture of form can be produced by a circulation of visual purple even if we assume, in Edridge-Green's sense, that it occurs. A consideration of the function of the visual purple as a photo-sensitiser and its part in photo-electric theory brings other difficulties which it is

unnecessary to discuss. The same remarks are applicable to Barrett's reference to visual purple, which appears to have been overlooked by other writers, and is quoted later as another example of an out-of-focus presentation of the retro-retinal circulation.

The Seat of Vision for Form

Arey says (p. 775) "the exact level of the image in the retina and by assumption the level where the transformation from light energy to nervous excitation takes place is not surely known." The parallax experiments of H. Müller (1855) with Purkyně's figure showed that it occurs in the pigment epithelium or between it and the outer nuclear layer. Much controversy has followed since, but the position has not been more clearly defined; and within recent years different investigators have assigned to it the three possible positions, namely, the inner segment of the rods and cones, the outer segment of the rods and cones, and the pigment layer of the retina. Lindsay Johnson thought that the image was formed behind the retina on the brilliant surface of the tapetum or the fusca pigment layer of the choroid and was then reflected back on to the bacillary layer; and Zoth concludes that there is a primary energy transformation in the pigment epithelium and a secondary energy transformation in the rods and cones presumably in the outer segments. Hess would seem to place the transformation in the outer and Arey in the inner segments.

The visibility of the chorio-capillaris and the retinal pigment should allow us to state the seat of energy transformation resulting in vision more accurately than heretofore. Since the retinal pigment can be viewed entoptically the seat of the transformation of energy cannot be in the retinal pigment layer. Whether it is in the inner or outer segment of the rods and cones is more difficult to decide. If we could be certain of the magnification and position of any two structures, one in front and one behind the seat of energy transformation, the riddle might be solved. But these criteria are not readily ascertained, especially as regards the magnification under which structures in front of the rods and cones are seen. The chorio-capillaris projected in the field of the microscope at approximately 10 inches distance, is observed entoptically under a magnification of about 100 diameters. This figure was obtained as a result of observing a section of the human retina under the microscope and adjusting the magnification so that the size of the retinal pigment is the same as that of the pigment seen entoptically when the slide is moved out of the field. The same method when applied to structures in front of the rods and cones gives

a larger experimental error which makes a comparison of questionable value. The capillaries viewed entoptically are the surface capillaries of the retina and are seen under too small a magnification for their diameter to be gauged. And, mainly owing to their luminosity, it is not easy to estimate the size of the luminous points which, for reasons already advanced, have been placed in the capillaries of the inner nuclear layer. They are said by Ebbecke to appear 2 mm. in diameter at a projected distance of 25 cm. My own observations make them not more than 1 mm. at two metres distance. It is thus obvious that the angular size of these points as estimated by comparison with external objects is liable to great variation. A note from Dr. H. Moore says "An obstacle on the retina of size 7.5μ would produce a black spot having an angular size of $1/2,000$ radians or appearing as large as a spot 1 mm. in diameter when viewed at a distance of two metres." If this estimate of 1 mm. size at two metres distance is correct it suggests that these darting points are caused by blood corpuscles.

The visibility alone of retro-retinal structures seems to afford a more reliable guide to the position of the transformation although offering difficulties of its own. Little stress can be laid on the fact that the chorio-capillary circulation may appear under somewhat different magnification by different methods of observation since this matter is capable of more than one explanation, but if it is permissible to use those accidental and rare observations of pigment granules under high magnification when the eye is practised to observed retro-retinal structures the question is simpler. Zehender estimated the granules he saw as 2 mm. in length. The crystals seen on two occasions by me appeared to be at least 1 mm. long projected to 10 inches distance. Measurement of the fuscine crystals on my own slides of the human retina gave an average length of $2\mu^*$ so that the magnification under which the crystals were seen entoptically was at least $\times 500$. This magnification places the plane of energy transformation in the outer segment of the foveal cones. But apart from the magnification under which it may be observed it appears to me that the mere visibility of the chorio-capillaris supports the view that energy transformation occurs in the outer segment. The fibrous body between the inner and outer segments of the rods and cones must have some function. Its form as usually figured suggests that it may have some condensing action on the light rays proceeding from the surface of the retina to the outer segment and if it

* Arey (p. 748) gives the length of fuscine crystals as $1\mu-5\mu$ but it is doubtful if the latter length is ever reached in man. My own measurements of definitely discrete crystals gave much narrower limits, namely, 1.5μ to 2.5μ . Longer measurements are probably due to two or more crystals in alignment which is not uncommon and is often difficult to recognise.

possesses this function it would tend to prevent the formation of an image proceeding from the back of the eye on the inner segment. Therefore it seems probable that the outer segment is the seat of the transformation of light energy to nervous excitation; and it is also probable that the transformation occurs throughout a considerable depth, perhaps throughout the whole of the outer segment, so that any plane may be a percipient part; otherwise it would be difficult to explain some of the observations recorded in this paper or the perception of chiaroscuro. Moreover, there seems to be an appreciation of depth in viewing the retro-retinal circulation, partly perhaps due to the magnification under which it is seen, which is difficult to understand unless perception is possible through some thickness of the rods and cones.

Comments

The literature of entoptic phenomena, even of that dealing with the problems under discussion, is voluminous. It is not intended to criticise it. Nearly all of it has been written from the point of view that the human eye can only function in an inverted form and that the only circulatory phenomena perceptible are those likely to be associated with the retinal vessels. And yet these vessels can be observed entoptically, except as pressure phenomena, no more than momentarily unless they are in constant movement relative to the light source. It is, however, evident from the literature that most investigators have dimly perceived out-of-focus presentations of the chorio-capillary circulation without recognizing the significance of their observations. A quotation from Barrett's paper (p. 129) will serve as an example: "After the eye has been in complete darkness for some time a curious entoptic phenomenon can be seen when a lighted candle is held near the eye. Numerous streams and patches of what seems to be a light flocculent matter will be seen quickly moving on a dark purple background which covers the field of vision. The appearance somewhat resembles a very brisk agitation and settling of curds in a purple whey. In the course of half a minute or less the moving flocculent streams clear off and the retina assumes its normal state. The experiment is best made after waking up in the night and immediately after lighting a bedside candle. It is possible that the phenomenon, which does not appear to be mentioned by any writer on physiological optics, may be connected with the presence of the visual purple in the retina." The last point has been dealt with previously. The streams and brisk agitation can only be appreciated by one who has seen the retro-retinal circulation. Three investigators have ascribed the circulation seen to the chorio-capillaris. Vierordt (1856) first observed it as

a pressure phosphene and with rapid intermittent illumination, but later he saw it in the dark without any artificial aid. The matter was investigated further by his pupil Laiblin (1858) whose thesis, referred to by Vierordt and by Zehender, I have been unable to obtain. Zehender (1895), like myself, was looking for entoptic effects which could be seen without distorting the eye. He describes the occurrence of scintillating points seen with closed eyes on awakening in the morning and later he observed the retro-retinal circulation in this way. He says one does not see this blood circulation when in complete darkness, but one sees it with very little light from outside as, for example, through closed eyelids.

Vierordt offers no explanation of the phenomenon. How the appearance of circulating blood corpuscles produced by pressure on the eyeball without the mediation of objective light is possible is, he says, one of the great riddles of the physiology of vision. Zehender explained the sensation of points of light as possibly due to the blood corpuscles in the layer adjacent to the rods and cones exerting sufficient pressure on these to produce the sensation of light—he calls them microscopic phosphenes. As he could not conceive of the retro-retinal circulation being seen without some illumination he concluded that the illumination was provided by the self-light of the eye which he attributed to cell combustion, although he apparently thought that chemical changes associated with the pigment granules also play a part. He says (p. 350): "It appears that physiology permits the assumption that the 'explosions' in animal cells which develop CO_2 are accompanied not only by local rises of temperature but also by the production of light. And hence it may be that such explosions in the retro-retinal cells are accompanied by the development of light. There is thus within the eye a constant light source—a burning torch—which enables retro-retinal things to be seen; and the objection that the blood circulation in the chorio-capillaris cannot be seen because it is in the dark behind the pigment layer is removed." And later (p. 379): "If we may assume as probable light and phosphorescence as occurring in the retro-retinal region, then we are able to explain other visual perceptions. If there is sufficient light and brightness at the back of the eye to see the capillaries and the choroid then there must be sufficient to perceive in great magnification the pigment epithelial layer between the retina and the choroid. Under favourable conditions the fuscine particles in the pigment cells and the movement in them could be clearly seen." On one occasion he appears to have seen a small clump of pigment break up into three rod-like particles although he saw no light changes occur with it. I have not been able from casual observation to see the chorio-capillary circulation by

Vierordt's method of intermittent illumination, but have frequently obtained it as a pressure phosphene. Recent criticism, particularly by Scheerer and Ebbecke, has thrown doubt on Vierordt and Zehender's observations. Ebbecke says (p. 247): "That notwithstanding numerous endeavours their observations still remain unconfirmed," and later (p. 265): "One finds no sufficient criteria for the entoptic perception of structures of the choroid or of the pigment epithelium." Anyone who has properly seen these structures can be in no possible doubt on the point. Whether, as Scheerer seems to suggest, the ability to see retro-retinal structures is limited to elderly people—Zehender was 75, I was 63, but Vierordt was only 38 years of age when observations were made—is a matter for further investigation. A more important question is how are these structures seen? Most of my own observations were made before looking into the literature of the subject and they led me to conceptions which apparently have not yet been expressed. Reason has been given for regarding the outer segment of the rods and foveal cones as the seat of energy transformation for visual form. If this be accepted we have to explain how the outer segment is able to see retro-retinal things. In all probability the rods and foveal cones have slightly rounded ends, and most planes of the outer segment and not any particular one are capable of visual perception. Apparently the end of the outer segment comes into approximate focus with the things seen, and since even the lowest magnification, that is the vision of the most distal object, the chorio-capillaris, is roughly $\times 100$, it follows that the ends of the outer segments must come almost into apposition with the retro-retinal structures observed. When the pigment of the retinal epithelium is seen under higher magnification the apposition must be still closer. This adjustment of the outer segment is possibly controlled by the contraction and relaxation of the myoid of the inner segment. If this point is allowed there seems to be little difficulty in explaining the various phenomena. The contraction of the myoid in animals in which it has been observed appears, however, to have been leisurely; in man it must be assumed to be rapid, or at least to be capable of great rapidity. Garten suggests that it may occur too rapidly in man for fixation.

Evidence in support of a state of relaxation in the layer of rods and cones may be obtained from visual observations made immediately on awakening from sleep in a dark room. The retinal pigment may usually be seen under these conditions. The most successful plan in my own case has been to turn the face with the eyelids, still closed, towards an electric globe a metre or so above the bed and switching the light on. There appears at first a haze of light sometimes with indefinite starry points at the

periphery followed in about a second by a field of fine pigment granules often associated with a geometrical pattern lasting one or two seconds and being replaced by another haze of light. The effect can be seen with open eyes if sufficient bedclothes be pulled over the face to reduce the intensity of light to the small value required. If the eye is not completely dark-adapted by sleep the pigment granules are not seen, but under certain conditions a honeycomb or maculated pattern may be indistinctly observed or an out-of-focus picture of imbricated circles or a punctate or other effect. If the light is turned off before the retinal pigment picture has faded away violet dots irregularly scattered over the central field and occupying about two-fifths of the visible area may be seen. The dots are probably projected presentations of the rods and foveal cones. The surround is usually indefinite, but very rarely an hexagonal form was observed similar to the surface projections figured by Max Schultze (*Taf.*, Vol. XIII, Fig. 2) and others as that outside the area of the fovea. The appearance may be explained by the ordinary cones with short outer segments being unable to look backwards owing to their inability to focus retro-retinal structures of distinct contour because they are unable to extend sufficiently far back or because of their conical form. The ability to look backwards is probably limited to the rods and foveal cones and is much more noticeable in the latter than in the former, in part because they control the central area of the retro-retinal field, which apparently is the seat of acutest perception in retro-retinal as in normal vision, and possibly in part because of their great length which confers on them greater depth for visual perception and greater power of movement. For experiments of this nature complete dark-adaptation is necessary and this completeness can only be obtained by sleep in a dark room.

These and other observations suggested that during sleep the myoid of the inner segment relaxes and allows the outer segment of the rods and foveal cones to come into closer relation with neuro-retinal structures. On awakening, if the proper small intensity of light, as through closed eyelids, falls on the retina, the pigment is seen for a second or two probably as the myoid, contracting under the stimulus of the light rays, causes the outer segment to come into suitable position to receive the image of the pigment granules on one or more of its percipient planes. Further contraction which continues even with this small intensity of light causes the pigment granules to become out-of-focus and to be no longer seen. The effect can be observed only within narrow limits of a small intensity of light. So far it has not been possible to arrange a light intensity small enough to keep the pigment granules in focus for any length of time. Very rarely a fuscine crystal has momentarily been observed highly magnified in this way,

and on one occasion I saw what seemed to be fuscine crystals gradually replaced by granules as though one were focusing a camera from an anterior layer of crystals to a posterior layer of granules before the latter finally disappeared. This phenomenon seems explicable only on the assumption that something was contracting and withdrawing the end of the foveal cone from the pigment layers. As stated previously, Zehender noticed movement when he saw the pigment granules highly magnified, but I was not so fortunate.

The question arises how retro-retinal structures are sufficiently lit to be seen by the outer segment of the foveal cones. Since the chorio-capillaris can be observed, in part at least, apparently self-illuminated by deep pressure on the eyeball the simplest explanation of the light source necessary to view the retro-retinal circulation is the self-light of the circulation itself; but in all Zehender's and my own observations, except the experiments on pressure phosphenes, the lighting has been from without. It would thus seem as if the retro-retinal circulation is seen by transmitted and reflected light combined. Light rays from outside appear to be totally reflected in the rods and cones (H. Müller, p. 101; Garten, p. 99; see, however, Klein, 1911). Probably a large proportion of the rays pass through the retina and lighting up the pigment layer and adjoining chorio-capillaris allow them to be observed in the same way as a vertical illuminator allows one to light and observe an opaque surface with the microscope. This process would best explain the way in which the chorio-capillary circulation is seen by the microscope lighting or opal glass lighting described. In these observations some relaxation of the myoid or other structure involved is necessary to bring the outer segment into proper position for observation; and it seems probable that the reason why the chorio-capillaris has not been observed more frequently may be the inability of most people to obtain this necessary relaxation, while the ability to produce it may be greater in age than in youth. This essential relaxation is accompanied by a feeling of slight strain and is not merely the sensation of rest from relaxed accommodation. The relaxation of the myoid, or whatever the process which is involved may be in this class of observation, is capable of training. This result has been noticed by most experimenters. After considerable practice I am able to see the retro-retinal circulation whenever I put my eyes to a microscope and I have become able to see it against almost any uniform white or grey surface. On the other hand after ceasing observations for some time retro-retinal pictures, especially the pigment ones, are more difficult to obtain.

But what becomes of the light rays that are still falling on the retina after the change from a bright visual field to one that

has been compared to dark-ground? The effect is probably akin to that in which an object on a bright field when intently gazed at with fixed eyes disappears and the field is replaced by one of a dim grey. This result is usually attributed to fatigue, but that cannot be the explanation in retro-retinal observations nor can the loss of light be explained by scattering. Can it be that the extension of the outer segments allows the light rays to pass through the rods and foveal cones and become almost wholly absorbed by the retinal pigment and choroidal circulations and in the process light up these retro-retinal structures more effectively? To whatever the transition from light to dark-ground effect may be due it is comparable in some measure with the change from photopic to scotopic vision. The perception of retro-retinal structures only occurs in light of low intensity.

It is not proposed to discuss the bearing on the theories of vision of the fact that the retina can look backwards, but its relation to the duplicity theory may be referred to since this theory does not seem to be applicable when the retina looks backwards. Vision in this direction has been compared with scotopic vision and it is well performed by the foveal cones. It is difficult to explain the anomaly that the fovea is night blind in normal vision and very sensitive to small intensities of light when looking backwards. Is the fibrous body of importance here also?

Much more might be added on entoptic phenomena associated with the retina. The effects obtained by intermittent illumination which have been productive of many interesting observations (Czermak, Exner, Charpentier, Nuel, Edridge-Green, and others) have not been considered and no mention has been made of the "blue arcs" or of the effects which may be observed with polarized light, mainly because the investigation was primarily concerned with the ability of the rods and foveal cones to look backwards. This faculty of the rods and cones seems to explain much that is otherwise obscure in the literature. The causes of many if not all entoptic phenomena not hitherto understood are probably to be found in the normal structures of the eye. Appearances which are common to different individuals must have an objective basis; and all structures which theoretically we might expect to see may be observed under conditions which can be reproduced or which may occur through chance observations not repeatable at will. For most persons who are unable to relax sufficiently, the structures merely form a basis for shadowy or out-of-focus presentations which nevertheless may be explained from our knowledge of these structures and the behaviour of light rays in the retina. The shimmering which may often be seen on awakening in the morning against any flat structure, such as the ceiling, reflecting the proper low intensity of light for the

purpose, is certainly produced by the retinal pigment and the chorio-capillary circulation. It is interesting to watch it wax with the increasing light of the dawn and diminish as the light grows stronger, although it still may be seen for a period in the shadows of the room. Entoptic phenomena which are not common to individuals may be due to pathological changes or to subjective effects. Of the latter probably every grade may occur up to a complete eidetic state; but with memory pictures and other similar conceptions entoptic phenomena are not primarily concerned.

Summary

The rods and foveal cones can look backwards and observe the retinal pigment and chorio-capillary circulation.

On rare and chance occasions the retinal pigment may be seen under different and high magnifications.

The difficulties of observation and different appearances are attributed to varying positions of the outer segment, possibly caused by greater or less relaxation of the myoid of the inner segment, of the rods and cones.

The outer segment is regarded as the seat of transformation of light energy to nervous excitation.

The darting luminous points are attributed to red blood corpuscles in the capillaries of the inner nuclear layer.

The self-light of the eye is probably associated with energy emanating from the pigment particles of the retina and from the retro-retinal circulation.

Most unexplained entoptic appearances associated with the retina, except those which may be due to or influenced by the mentality, especially the powers of pictorial conception, of the individual, are explained as out-of-focus presentations of normal structures in or adjoining the retina.

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ORBITAL TERATOMA

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ORBITAL teratomata are very rare tumours, and in ophthalmic literature I am only able to find 12 cases which so far have been reported. They are congenital, grow very rapidly, the child as a rule dying in the first few weeks of life. They may also occur in the form of a cystic tumour. The tumour consists of the derivatives of two or three germinal layers.

The Marchand-Bonnet theory best explains the formation of these tumours. During the early development of the embryo, the blastomere severed from its connections may remain as a